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Bio-Inspired Routing Approaches for Flying Ad-Hoc Networks: A Comprehensive Review

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Abstract. The use of wireless networks Flying ad hoc networks, also known as FANETs, are a versatile technology that is utilised for the purpose of constructing remote communication infrastructure and doing surveillance operations. Flying nodes without steady infrastructure may usually connect within a limited wireless range. FANET routing protocols can be improved with bio-inspired algorithms. This research investigates the application of a bio-inspired algorithm to improve FANET routing systems in various contexts, thereby enhancing the dependability, effectiveness, and robustness of communication networks. FANETs' high mobility, bandwidth constraints, and energy constraints must be considered when creating and implementing these algorithms. FANET's mobility and energy limits necessitate creative routing. This article uses bio-inspired algorithms to enhance and examine nature-inspired techniques' strengths and adaptability to present an overview of FANET routing.

Keywords: *FANET, Wireless network, Bio-inspired algorithm, Routing data.*

Introduction

The functions that aerial communication networks are intended to fulfil are both specialized and immediate. Unmanned aerial vehicles (UAVs) are the components that make up FANETs, which are wireless networks that are formed by establishing links to build a mobile network for communication purposes. The capability of ad hoc networks to communicate without relying on infrastructure has been enhanced because of recent attention. can autonomously construct networks to meet various communication requirements [1].

FANET is promising for safety, monitoring, emergency response, and agricultural fields. Stable connection and effective data transfer require routing protocols. Due to their mobility, instability, and unknown environments, FANETs pose unique challenges [2]. Bio-inspired strategies optimize FANET routing characteristics by utilizing natural systems' effectiveness and adaptability. FANET refers to a network of UAVs that communicate wirelessly in an ad hoc fashion. Connectivity for expanding the network is provided by specific UAVs that can serve as link between base control and other UAVs [3]. This network is widely used in the military, civic, and commercial sectors due to rapid electronics and communication technology advancements. In the media and entertainment industry, object tracking, epidemic detection, monitoring, and other applications are helping the UAV market grow. Flying nodes send data to many wireless devices at critical locations. Due to their many benefits of saving

time, cutting costs, improving results, and improving safety, academics and industry are interested in FANETs [4].

FANETs, made up of drones or UAVs, have garnered attention for their potential in many fields. Traditional routing protocols struggle to adapt to FANETs' dynamic and unpredictable nature. Bio-inspired algorithms, drawing inspiration from nature, offer promising solutions to address these challenges [5]. This review synthesizes the current state of research in applying bio-inspired algorithms to enhance FANET routing.

Contribution of the Research

1-Covering the FANET properties, communication, and application. Also illustrates FANET routing in smart cities.

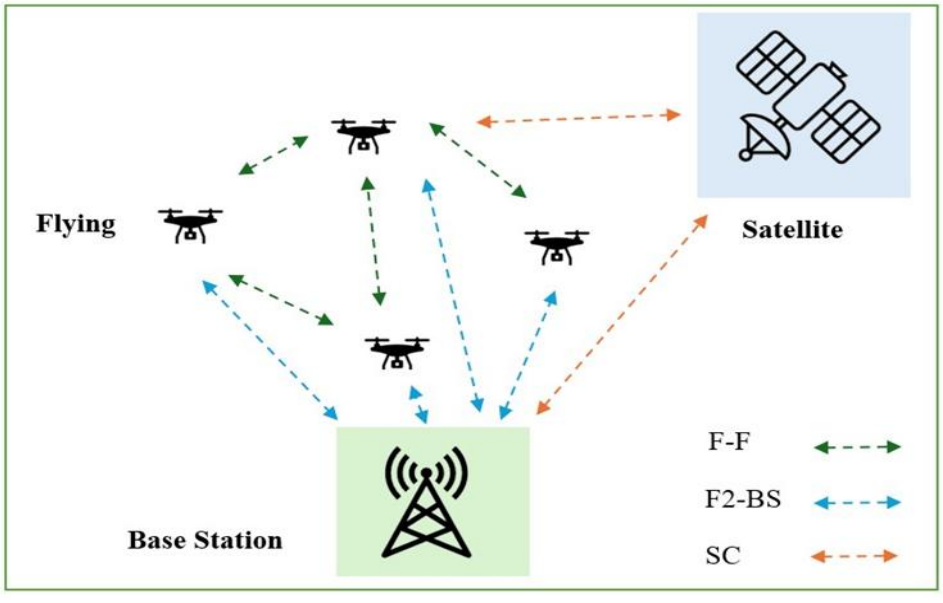
2-Employing bio-inspired algorithms to enhance FANETs' routing protocols to consider the distinctive features of FANETs, like high mobility, constrained bandwidth, and energy restrictions, while developing and putting these algorithms into practice.

3-Addressing the restricted bandwidth and energy restrictions in the FANETs network for routing protocols.

The organization of the paper in section II represents the Related work, in section III the system model, in section IV provides the result and the end section represents the Conclusion and future work.

FANET Overview

FANET is an autonomous network of UAVs and ground base stations (GBSs) without preexisting communication. These entities should communicate ad hoc using UAVs and GBSs to transmit data as described in Figure 1. This system typically chooses UAVs with extra features to act as gateways among GBSs and other UAVs, significantly expanding network coverage. In addition, various communication methods, network structures, and features are necessary for various applications [6]. Three subsections make up this section. The first section covers the most used FANET characteristics in the literature. Second, FANET communication, and finally FANET application are covered.



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Figure 1. FANET Communication.

FANET Characteristics

A-Mobility:

FANET moves UAVs or drones, making them dynamic and mobile. Network node mobility complicates communication and routing. FANET creates temporary, self-configuring networks without infrastructure. Drones in the network communicate to establish and maintain connections [7].

B- Limited Energy Communication Range:

FANET prioritizes energy efficiency because drones use batteries. Drones need efficient routing and communication protocols to save energy and fly longer. The drone communication range in FANET depends on altitude, interference, and environment. Adjustable routing algorithms are needed for changing communication ranges [8].

C-Dynamic Unpredictable Network Topology:

FANET's topology changes quickly due to drone mobility. Routing protocols must adapt quickly to topology changes to ensure efficient and reliable communication. FANET often works in unstable environments like cities, disaster zones, and low-resource areas. Negative conditions must not disrupt the network [9]. As presented in Figure 2.

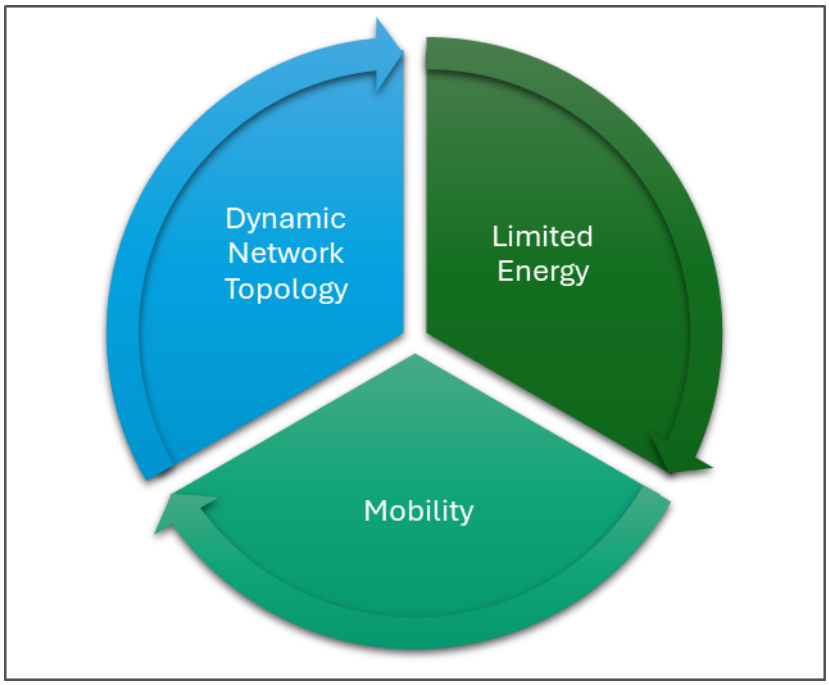


Figure 2. FANET Main Characteristics.

FANET Communication

FANET's organizations state that each node (like, UAV, GBS, Satellites) can function as an end system. Several restrictions exist when two distant nodes communicate, including sudden disconnections,

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packet losses, and network fragmentation. FANETs allow drones and UAVs to communicate using various methods [10][11].

A-Ad-Hoc Communication: Ad-hoc communication dominates FANETs. It uses peer-to-peer communication between UAVs in the network without infrastructure. Drones can dynamically exchange data, control commands, and route information using ad-hoc communication.

B-Multi-Hop Communication: Data is sent through multiple hops to reach its destination in multi-hop communication. UAVs in FANETs can use multi-hop communication to overcome obstacles, increase range, and improve network coverage. Connectivity in dynamic and challenging environments requires multi-hop communication.

C-Control and Command Communication: UAV-ground control station control and command communication sends instructions, commands, and control signals. Remotely piloting drones, updating flight plans, and coordinating FANET mission-critical tasks require this communication.

FANET Application

FANET research is focused on addressing its challenges and expanding its applications in various domains. As technology advances, Applications of FANET, such as surveillance, disaster response, and communication relay, often require real-time data exchange. Low latency and reliable communication are crucial for the success of these applications. ANET is likely to play an increasingly significant role in diverse fields including [12][13]:

A-Surveillance and Monitoring:

FANET provides real-time aerial views for surveillance and monitoring. This app aids security, law enforcement, and disaster response. FANET can quickly survey large areas and identify survivors and emergency areas in disaster situations. Drones' mobility allows rapid deployment. FANET drones can track wildlife, air quality, and pollution. This data aids environmental research and conservation. FANET can monitor crops, assess soil conditions, and optimize farming practices in precision agriculture. Sensor-equipped drones can help manage crops.

B- Communication Infrastructure:

FANET drones can relay communication for ground-based devices in remote or disaster-stricken areas without infrastructure. FANET can provide temporary communication in remote areas without traditional networks. Drones can communicate via ad-hoc networks. FANET drones can perform light and aerial shows at events and entertainment shows. Drone synchronization can create stunning and dynamic displays.

Table 1. Characteristics of MANET, VANET, and FANET.

System	MANET	VANET	FANET
Type of node	Sensor, PC	Car, Bus	Drone, Aircraft
Speed of node	Static around (0-5) km	Medium to high (40 -180) km/h	Low to High (10-450 km/h)
Density of node	Low to medium	high	low
Mobility	static	Regular	free
Connectivity	medium	high	low

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Wireless Technology	IEEE 802.15.4	IEEE 802.11p	IEEE 802.11 a/b/g/p
Freq Band	2.4 GHz	5.9 GHz	2.4/5 GHz

FANET Routing

In routing operation links interruptions and dynamicity make routing protocols intended for ad hoc systems unsuitable for FANETs. Because of power constraints or malfunctions, Drones in FANETs may often leave and re-enter. UAVs' mobility allows for faster coverage, resulting in lower node density in FANETs compared to MANETs and VANETs. Nevertheless, frequent network partitioning poses a challenge. These qualities make conventional routing algorithms unsuitable for FANET [14].

Along with MANETs and VANETs, FANETs need routing protocols that specifically address their requirements. This section outlines FANET routing protocol classifications from the literature.

A-Topology Routing

This routing scheme sends data packets using network node topology. A suitable routing path is necessary for data transmission from source to destination. Using an addressing approach, this routing scheme assigns equal roles to all participating UAVs. The routing schemes in the network are classified as proactive, reactive, or hybrid based on how UAVs obtain and maintain routing information [15].

1-Proactive type

This routing scheme keeps the most recent navigational data for all UAVs in the entire network, regardless of the circumstances, regardless of whether they possess information packets to transmit. Information about UAV routing tables is periodically updated and distributed among UAVs that are connected to a network. This category groups routing protocols by approach, such as OLSR.

2- Reactive type

The on-demand protocols only discover a route if it can send data packets but there is no routing path in the network that leads to the UAV that is the destination. It addresses bandwidth and power consumption limitations of proactive routing schemes by reducing route management overhead. A flooding technique is used for route discovery when all nearby UAVs receive a route request message from a source. After receiving the RREQ packet, neighbor UAVs rebroadcast it to their neighbors up until it gets to the destination that is meant to be there or an intermediate node that has a path there. Route reply packets are sent to the originating UAV by either side. The interaction starts immediately as the source UAV gets the response packet. These routing protocols only store active route information such as Robust and Reliable Predictive routing protocols.

3- Hybrid Type

The hybrid routing schemes combine proactive and reactive routing features. This was invented to solve the overhead in proactive routing and the delay in reactive schemes brought on by route exploration. This category presents proposed routing protocols for FANETs such as A hybrid routing algorithm (HRA).

B-Geographic Routing

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Geographic routing uses node positions to forward data packets. Every UAV is supposed to use its GPS or other positioning system to identify its location. This routing system forward data packets using local information instead of network information. Additionally, route discovery floods and routing tables are unnecessary. Each node needs little routing information. Thus, improve network performance. Because UAVs are mobile and have dynamic missions, FANETs may benefit from geographic routing protocols. To arrive at decisions regarding routing, only the positions of the neighboring and destination UAVs are required. This routing uses greedy packet forwarding and a recovery mechanism for greedy failures. Greedy forwarding involves sending packets to the neighbor node the shortest distance to the destination [16].

FANET Bio-inspired Routing Protocol

Bio-inspired algorithms can improve FANET routing by using nature's principles and strategies to improve efficiency and adaptability. Bio-inspired algorithms often draw inspiration from the behavior of biological systems to enhance FANET routing algorithms. Use bio-inspired self-organization and adaptation in routing protocols. Nodes can self-adapt to network dynamics. When applying bio-inspired algorithms to FANET routing, aerial ad-hoc network characteristics and needs must be considered. Simulation and experimentation can enhance parameters and evaluate bio-inspired routing algorithms in FANETs [17].

Since they can solve difficult routing issues in FANETs, bio-inspired algorithms have drawn a lot of interest lately. These are inspired by the behavior of natural systems, such as ant colonies, bird flocking, and bacterial foraging, and are effective in solving optimization problems in various domains. Efficient routing poses a significant obstacle in ad hoc networks. Traditional routing protocols face challenges in achieving load balancing and efficient routing in dynamic and resource-limited contexts. To find a solution to this issue, researchers are employing routing algorithms that are inspired by biological systems in flying ad hoc networks [18].

The FANET routing process is optimized by bio-inspired algorithms, which discover the shortest path between two nodes. This helps to balance the load on the network and improve performance. since of this, these algorithms are perfect for FANET routing since they can adjust to different network topologies and situations throughout the network.

Related Work in Bio-inspired FANET Routing

Experiments and simulations can evaluate bioinspired FANET routing algorithms against current protocols for dynamic network adaptation, latency, energy efficiency, and packet delivery. This section will cover the FANET routing algorithm that is the most bio-inspired of all the algorithms used.

In [19] Recommended FANET routing scheme, inspired by biological systems. The protocol uses AODV route computation to maintain connectivity and route maintenance throughout data transmission. FANET uses these networks to improve cooperation and efficiency ad hoc, enabling unique tasks in specific environments. The study in [20] intends to solve this with effective clustering. by adopting a bio-inspired FANET clustering method that blends GSO approach. The proposed methodology utilizes the GSO algorithm to facilitate energy-conscious cluster creation and head selection. Furthermore, offering a proficient cluster management technique.

In [21] explore FANET in accurate farming to combat parasites and climate change that lower product quality. These developments can help farmers combat threats and kill parasites that harm plants in cultivated fields. This work presents a bio-inspired recruiting procedure, demonstrating its performance by adjusting algorithm parameters for optimal implementation. In [22] Self-organization

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based on glowworm swarm optimization (GSO) is proposed for cluster management. Connectivity to the ground control station, in FANET residual energy, determines cluster head election and formation. Cluster management utilizes GSO behavioral analysis to update the FANET position. and suggest a route selection mechanism that utilizes UAV neighbor range, residual energy, and position for efficient communication.

The researchers in [23] presented a Bio-inspired FANET coordinating framework for agriculture proposed in the paper. when parasites and sudden climatic changes degrade crops and cultivation quality in precision agriculture. New technologies like FANET with sensor actuators can help smart agriculture. The proper leadership and collaboration of these novel technologies are crucial to planning strategies to support agriculture operators. Scalable coordinating methods may enhance network performance and task execution efficiency because drones are resource constrained.

In [24] effective protocols for controlling FANET against crop parasites were examined. Researching various methods to evaluate their effectiveness and cost. One issue with these devices is limited fuel and pesticide supplies. to deal with this problem by FANET nodes to help get rid of the parasites. What's being proposed is to use bio-inspired ideas to improve the hiring process and performance reviews so that the proposal works well. The article in [25] describes a new protocol for FANET routing that uses the Ant colony optimization method and is more reliable and faster than older best path selection methods. Adding an energy-stabilizing parameter to this study makes the network work better and uses less energy.

The authors in [26] suggest an effective self-organization model for FANET this combines a mobility framework with a cluster-based distribution algorithm using bio-inspired approaches and energy efficiency in a system scenario improved by two-level data aggregation. Through simulations, our proposed model showed that it could effectively lower energy use, resulting in a longer network lifetime. In [27] A new FANET clustering protocol for routing uses node location. Fusing variable neighborhood search yields an enhanced particle swarm technique that improves UAV locating precision. Averaging intra-cluster lifetime and residual energy, the main station (MS) equally clusters UAVs according to node position. To ensure timely and reliable data transmission to the MS, IPSO selects the optimal next-hop routing based on link reliability and node distance.

The study in [28] suggested the Gray Wolf Algorithm for FANETs is proposed in this paper to control gray wolves' social hierarchy and collaboration. designing GWO for flying nodes and imagining cooperative diversity with two relays supporting either source-to-destination link. Protocol design is novel by using cooperation techniques for FANETs in this scenario. In [29] propose bio-inspired localization with clustering techniques for wildlife monitoring and tracking in FANET networks. by developing a hybrid method and energy-efficient algorithm. This approach minimizes localization errors, reaches high accuracy, and avoids confusion in restricted distance measurements.

The researchers in [30] present bio-inspired routing for diverse FANET swarm networking. Each swarm node builds cell walls like biological cells. The FANET swarm system can collaboration and cooperation within its connection range. Experiments demonstrate that bio-inspired algorithm enhances the effectiveness and resilience of diverse FANET swarm communication. The authors in [31] suggest an SDN-based heterogeneity framework for reliable communication in FANETs. In the FANET routing problems suggest the direction of Particle Swarming Optimization (DPSO) solution to select the optimal path to handle the frequent movement of flying and terrestrial clients can cause changes in network topology could enhance routing management and FANET continuous service reliability.

In [32] this article introduces a new method based on the Glowworm Swarm algorithm to solve path-planning in FANET without hitting dynamic and static obstacles. Adjusted paths are created after the

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first one has been created to optimize and smooth the trajectory. The suggested approach surpasses the alternative algorithm in dynamic path-planning environments, according to extensive experiments.

The study presented [33] A new clustering technique is offered. This system uses distributed multi-hop clustering. Inspired by Biomimetic algorithms foraging during cluster formation. To guarantee cluster cover and stability, the algorithm assesses link communication quality, residual energy, and link stability. Cluster stability is much increased by choosing as the cluster head a highly stable node within the n-hop range.

Bio-inspired algorithms have shown promise in FANET routing, but there are still issues. UAV mobility in FANETs makes it difficult to predict their movement, which can affect bio-inspired algorithms. Large-scale FANETs may not use these algorithms due to their computational complexity.

Table 2. Bio-inspired Algorithm for FANET Routing Protocol.

Ref NO	Bio-algorithm	APPLICATION	Advantage
[19]	Swarm Intelligence (SI)	Monitoring	Quality of service
[20]	Glowworm Swarm Optimization (GSO)	Cluster Management	Decreasing Delay
[21]	Glowworm Swarm Optimization (GSO)	Clustering Scheme	Energy and lifetime
[22]	Recruiting Bio-Inspired	Agriculture	Scalable network
[24]	Ant Colony Optimization (ACO)	Agriculture	Recruiting Protocol
[25]	Electric-Bio-inspired	Clustered Architecture	Energy saving
[26]	Ant Colony Optimization (ACO)	Random Way Point	Energy Efficient
[27]	Particle Swarming Optimization	Clustering Routing	Improve link reliability
[28]	Gray Wolf Algorithm	Cooperative Technique	transmission loss, energy consumption, and Quality of service.
[29]	Hybrid Gray Wolf optimization (HGWO)	Monitoring Wildfires	Energy-efficient
[30]	Swarm networking	Aircraft Systems	deployment heterogeneous network
[31]	Particle Swarming Optimization (PSO)	Mobility estimation and prediction	Quality of service parameters
[32]	Reverse Glowworm Swarm algorithm	path planning	minimum time complexity
[33]	Biomimetic algorithms	multi-hop clustering	Stability

Future Challenges for FANET Routing

Due to recent advances in UAV technology, such devices will become increasingly prevalent in all aspects of life. Technology can improve services and generate new uses. Successful UAV systems or services require ad-hoc networking [34].

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This system struggles with frequent disconnections, bandwidth, packet delay, and UAV energy capability. FANET routing challenges can be solved with bio-inspired algorithms. There are still certain obstacles to overcome to increase their performance. Some are here:

A-Routing Mobility

FANET UAVs move swiftly, making movement prediction challenging. Bio-inspired routing algorithms that predict mobility may fail. UAVs need P2P communications to collaborate and avoid collisions. Data-provider UAVs are ideal for P2P file sharing. FANET communications can be difficult to create new P2P techniques and converged traffic. An effective data exchange routing strategy is difficult to create because to UAVs' mobility and density. These issues worsen when UAVs move in 3D. Many approaches have been proposed for a specific network situation. They cannot address all network issues, such as those of FANET. Thus, new protocols are necessary to apply the correct approach in specific situations [35].

FANET topologies are highly dynamic due to UAV mobility. To maintain communication, routing protocols must quickly adapt to topology changes like node movements, link failures, and connectivity disruptions. Real-time surveillance, communication relay, and disaster response are emerging FANET applications with strict Quality of Service requirements. To meet application-specific needs, routing protocols must prioritize QoS metrics like latency, throughput, reliability, and jitter [36].

B-Energy Efficiency

FANET UAVs have a restricted battery life, making energy efficiency crucial. Bio-inspired routing algorithms must consider UAV energy consumption. The energy capacity of UAVs is limited by batteries. UAV battery technologies are constantly evolving to enable long flight times using green energy sources. Not meeting the long UAV distances and data traffic needs. The first option is for UAVs to collaborate to overcome energy constraints. Studying recharge station placement is the second option.

Energy efficiency is essential for FANET UAV flight time and endurance. To save energy, optimize route selection, and extend network life, routing algorithms should consider energy-aware metrics and strategies. UAV routing protocols must comply with regulatory, airspace, and safety requirements while ensuring efficient and reliable communication [37].

C-Data Security

Eavesdropping, jamming, and spoofing threaten FANETs. Bio-inspired algorithms must address security threats. Network security depends on vulnerability knowledge. Malicious UAVs make FANET security critical. Additionally, embedded autopilots in UAVs make them susceptible to cyber-attacks. Since the network layer supports most applications, this issue must be addressed. Identifying FANET problems to different attacks requires comprehensive research before suggesting security features.

Interception of critical UAV information by a malicious entity can have dire consequences for this network. To maintain confidentiality and integrity, cryptographic methods are used to convert readable information into meaningless data. This protection is complicated by UAVs' limited energy

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capacity and inefficient cryptographic calculations. As a result, creating unique security codes has been a challenge [38].

D. Integration with Other Technologies

FANETs can be integrated with 5G,6G networks, IoT, edge computing, and artificial intelligence (AI). To enable innovative applications and services and address interoperability and compatibility issues, routing protocols should integrate seamlessly with these technologies. Researchers, industry stakeholders, and regulators must work together to develop robust, efficient, and scalable FANET routing solutions to unlock aerial ad-hoc networks' full potential in various domains [39][40].

These challenges must be addressed to improve bio-inspired FANET routing algorithms. Research is underway to address these issues and improve FANET routing bio-inspired algorithms, as presented in the figure.

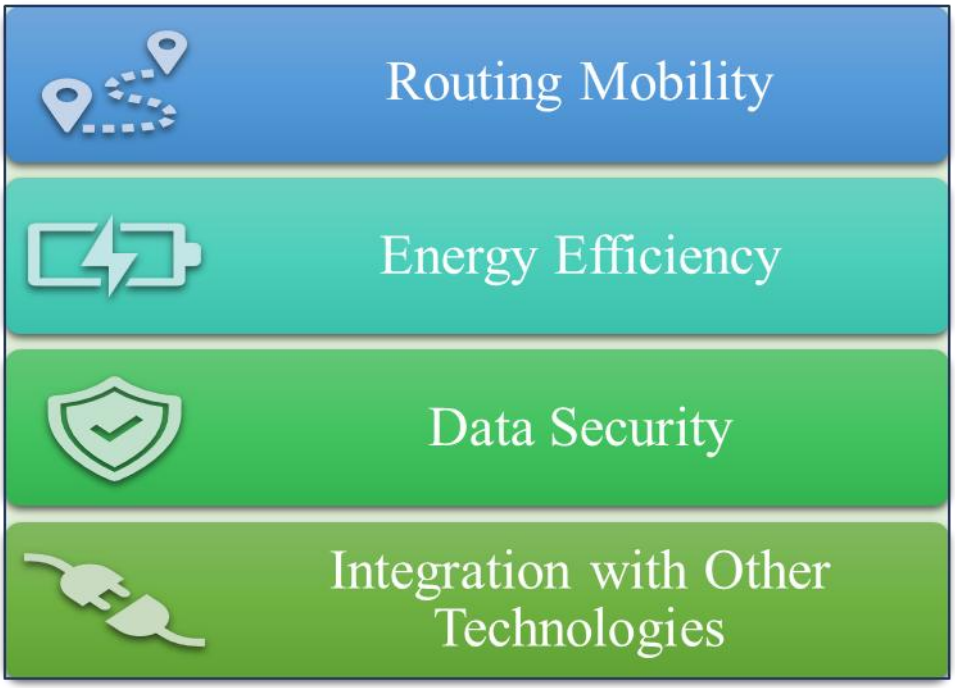


Figure 3. Future Challenges in FANET Routing.

CONCLUSION

In FANETs, the routing ensures proper functionality and efficient cooperative network operations. Bio-inspired FANET routing algorithms improve network adaptability, efficiency, and robustness. Exploring Swarm Intelligence in FANET routing helps build intelligent, self-adaptive aerial communication networks. This research may help FANETs overcome their unique challenges and maximize their potential in various applications. Complex FANET routing problems can be solved with bio-inspired algorithms. Natural system-inspired algorithms have been shown to solve optimization problems in various domains. However, some issues must be addressed to improve FANET routing performance. More efficient and effective bio-inspired algorithms are being researched. A thorough survey examined key factors affecting FANET routing using bio-inspired algorithms. First, briefly describe

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FANET decryption, including its characteristics and applications. After that the routing category is with example. Then, bio-inspired algorithms are explored for FANET routing. Scalability, security, and real-world implementation must be addressed to spread these innovative routing strategies. And identified understudied research challenges and requirements for FANET routing protocols.

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